Molecular Structure: From Lewis Dot Structure to Molecular Geometry

An Honors Thesis (HONRS 499)

by

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Purpose of Thesis

This report is of the results of a study designed to answer two questions. The first question is to understand why students have difficulty constructing three-dimensional molecular models from the two-dimensional Lewis structures. The second question is to identify ways in which instruction could be changed to improve the student's ability to carry out this task. Analysis of first semester general chemistry student interviews yielded the following findings. First, all the general chemistry students memorized the molecular geometry that corresponded to a specific Lewis structure. The students had little understanding of the origin of molecular geometries, the importance of shape, and the role of lone pairs of electrons. Second, having the students build representations of molecules helped them construct a more sophisticated understanding of molecules and chemical phenomena. These findings provide a basis for improved teaching methods and an understanding of student's misconceptions.

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CHAPTER I

REVIEW OF THE LITERATURE

Purpose

The purposes of this literature review are to provide (1) an overview of the misconceptions of the shape of molecules, (2) an overview of the research in student mental models of atoms and molecules, and (3) an overview of the difficulty levels and method of drawing two-dimensional pictures of molecules.

Misconceptions of the Shape of Molecules

Misconceptions in science is a focus of interest for most educators. Understanding how a student processes information can give educators the tools necessary to create effective instruction. Misconceptions about the shape of molecules are addressed by Peterson and Treagust (1989). Their research indicates that 22%-27% of the students in the project perceived the following as true:

Claim 1: "The shape of molecules is due only to the repulsion between the bonding electron pairs." The influence of the nonbonding electron pairs where not considered by these students as factor that effects the shape of the molecule. This claim was used to justify the linear structure of SCl_2 during the interviewing.

Claim 2: "The shape of molecules is due only to the repulsion between the nonbonding electron pairs." This claim was used to justify and to determine the V shape of SCl_2 .

Claim 3: "Bond polarity determines the shape of a molecule." Students responded with this explanation in determining the shape of NBr_3 with the polarity of the N-Br bond as the major factor for the shape of the molecule.

Looking further into misconceptions on molecular shape, Griffiths and Preston (1992) investigated the perceptions of Grade-12 students with water. Their results indicated that the students in the project perceived the following as true:

Claim 1 "Molecules within a phase have different shapes." The idea that molecules take on different shapes due to the phase implied that students didn't understand the nature of molecular structure and molecular bonding.

Claim 2: "Water molecules are flat." When looking at a two dimensional drawing, students identify the shape as "flat". The abstract thinking needed to make the connection between the drawing and a three dimensional perception was not made.

Claim 3: "Temperature, pressure, or the shape of the container may affect the shape of the molecule." Students used this idea as a way to justify the differences between the phases a molecule.

Student Mental Models of Atoms and Molecules

Students formulate ideas and perceptions of what atoms and molecules are like through the development of mental models. It is not possible to show the students an actual atom or molecule, so students rely upon the instruction from teachers and textbooks in addition to their prior knowledge to compose an image of atoms and molecules. Many analogies, metaphors, and models are used to help students identify with the size and shape of molecules. Unfortunately, students are unable to distinguish between what is an analogy and what is reality. An investigation by Harrison and Treagust (1996) addressed the mental models of atoms and molecules of secondary students and the implications from the research indicated the following:

1. "Atoms can be seen under really powerful microscopes." Students didn't have a true understanding of the nature of science and wanted to believe that scientists have formulated atomic and molecular models by actually viewing them. The concept that these models were generated from experimental results didn't connect with the students. The students weren't able to see that the diagrams were analogical models.

2. "An uncritical acceptance of contrasting models of the shape of atoms suggests that understanding in this domain is quite superficial." Students claimed to view atoms as spherical or round like a ball, yet 55% of those students preferred spatial diagrams to a ball model. Students have a preconceived notion of what atoms look like in conflict with what they understand as should be the correct perception. Students are saying atoms look a certain way, but they really see atoms in a different manner.

Drawing Two-Dimensional Pictures of Molecules

In order to predict a molecules shape and reactivity it is essential to first understand how to draw two-dimensional pictures of molecules by using the Lewis theory of chemical bond formation. Research on the difficulty of drawing two-dimensional pictures and overall challenges students encounter with the task of formulating Lewis structures was investigated by Brady, Milbury-Steen, and Burmeister (1990). Identifying sources of confusion can assist instructors in making the connection between drawing two-dimensional pictures and conceptualizing the shape of a molecule. The research of Brady, Milbury-Steen, and Burmeister (1990) indicated the following :

1. The ability of a student to choose the central atom relied upon the type of structure. Molecules that had three or more atoms have a central atom when there is only one atom of an element. This idea

was easy for most students. "This is really a disguised appeal to symmetry, since often the central atom is of one type and the peripherals are all of other types. (p. 492)" Identifying the central atom when more than one element was represented with one atom, such as FNO_3, students had increased confusion and difficulty. The use of electronegativities wasn't clearly understood and not often used as a method of identifying the central atom.

2. The student's ability to complete a valence shell of an atom was inconsistent. The students often memorized rules and focused on the exceptions to the rule therefore making the task quite difficult.

As a tool, the method of drawing Lewis structures was outlined by Ahmad and Omar (1992) for a general chemistry class. The only required prior knowledge necessary for this method was that of the trend in electronegativities and location of the elements on the periodic table. A checklist for instructors and students for constructing a two dimensional representation of a molecule was provided in five major steps:

Step 1: "Choose a central atom from the molecular formula. As a general rule, this would be the atom that is the least in electronegativity and its number. (p. 791)"

Step 2: "Construct a sigma skeletal structure by drawing a single bond connecting the central atom to each terminal atom. (p. 791)"

Step 3: "Three unshared (nonbonding) electron pairs are then added to complete the octet on each terminal atom (except H). All valence electrons should be accounted for, and if not, the remaining pair(s) are placed on the central atom to give a skeletal Lewis structure. (p. 791)"

Step 4: "Try to complete the octet on the central atom (if it has not been achieved) by moving to it one or more unshared electron pairs form the multivalent terminal atom(s) to form pi bond(s). (p. 791)"

Step 5: "Calculate the formal charge on each bonded atom in the sketched Lewis structure. A Lewis structure with no formal charge (zero residual charge) is given to any atom is preferable. More than eight electrons (bonding and nonbonding) may appear on the central atom made up of third period elements or higher. (p. 791)"

The studies located to date investigated the mental models students utilized to conceptualize atoms and molecules, and the difficulty students have in drawing two-dimensional diagrams of atom and molecules. The present study seeks to bridge the two ideas in order to learn about a missing link in learning. The first question is to understand why students have difficulty constructing molecular models from Lewis structures. The second question is to identify ways in which instruction could be changed to improve the student's ability to successfully carry out this task.

References

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CHAPTER II

METHODOLOGY

Theoretical Framework

In determining the best method of understanding what students are thinking and how they are processing the information to attempt to complete the task, interviewing the students and videotaping their construction of models was the chosen method. Interviewing the students allowed flexibility in questioning in order to fully understand the challenges and mental processes for drawing two-dimensional diagrams and building the molecular models. Videotaping investigated how students manipulated the tools given and can be connected to the mental process during the interview. The video also gave a second form of analysis in determining how students connect the two-dimensional picture to a concrete three-dimensional depiction of the molecule.

Description of the Participants

A pilot study of four general chemistry students was performed during the summer previous to this study. The pilot study provided a sounding board for further investigation. The participants were selected randomly from the general chemistry class after a laboratory exercise involving the practice of drawing Lewis structures and building molecular models. The participants included two women and two men, who had taken high school chemistry. The participants were given a series of molecules (H_2O, NH_3, PCl_5, SO_2) and asked to draw the Lewis structure. Participants were to identify any rules or guidelines while drawing the two-dimensional structure. After drawing the structure, the students were to build a molecular model using marshmallows and toothpicks. The only supplemental guide provided to the participant was a periodic table.

After the pilot study was reviewed, the study was replicated in the fall with another set of three general chemistry students. The process was the same with the interview and videotaping, but the three of types of molecules were altered (H_2O, SO_3^{-2}, CO_3, XeF_2). Yet, the difficulty level of each of the molecules remained the same according to Brady, Milbury-Steen, and Joseph (1990).

In addition to the pool of general chemistry students, a series of other people with advanced chemistry knowledge were interviewed and videotaped in the same method to be used in a comparative analysis. The additional group of participants included a professor of chemistry and three students with three years of advanced chemistry. The professor serves as one of the general chemistry instructors. The pool of students were selected from the physical chemistry class at random and on a voluntary basis.

Data Collection

The collection of data for this project included an interview and a set of two tasks which was videotaped. The tasks consisted of drawing the Lewis structure for each of four different molecules altered (H_2O, SO_3^{-2}, CO_3, XeF_2) at various difficulty levels and then building a molecular model of each of the four molecules using the tools of toothpicks and marshmallows. During the two tasks, many probing questions were asked to fully understand the thought process incurring in student's mind. Students were asked to think aloud during the tasks, but often they would consume themselves in thought and forget to continue speaking. The probing questions were used to induce speaking.

The videotape was use to observe nonverbal behavior in addition to analyze the methodology of how students completed the tasks. The videotape allowed for a thorough and repeated observation of the interview. Behaviors or dialogue that wasn't clearly stated through the transcripts can be further investigated through the viewing of the videotape.

Data Analysis

In the analysis of the data, there were two aspects of the investigation: drawing the Lewis structure and building the molecular model. These two tasks were the basis for the interview and can be utilized to identify misconceptions and specific challenges. Within each assignment, many smaller uncertainties were unfolded.

Looking at the Lewis structures, the transcripts and the video were evaluated for instances of appropriate use of the central atom, correct placement and use of electrons, and understanding of what the Lewis structure represents. The first question was in the selection of the correct central atom. Questioning students as to why they selected an element to be the central atom identified what concepts they were using. Distributing the proper number of valence electrons was the second question. Students were asked to explain how they knew how many electrons were being used and how they were to be disbursed on the Lewis structure. Knowledge of valence electrons and understanding of how to determine an element's number of valence electrons was essential to this task. Finally, the students were to discuss what the Lewis structure represented to them. By knowing what the Lewis structure depicts, the students should be able to make the connection between the drawing of the molecule and a molecular model.

Building the molecular model unveiled a different set of questions pertaining to various aspects of shape and placement of bonds. Students were first asked to identify the shape of the molecule after each model was built. Questions of why shape is important and what effects shape were then investigated. Lone pairs and multiple bonds were topics used in trying to identify factors that may effect shape. Marshmallows and toothpicks were provided as tools to predict shape. One important feature to note is that marshmallows don't have established holes for the placement of bonds. This task induced thought on where bonds occur and what effects the number of bonds.

Taking the two-dimensional picture and formulating a more sophisticated three-dimensional model provided the basis of the analysis. The investigation encompassed both aspects and provided a connection between the two tasks. The video and transcripts provided the data necessary in determining this analysis.

References

1. Brady, John A.; John N. Milbury-Steen; John L. Burmeister, Journal of Chemical Education, 1990, 67, 491-493.

CHAPTER III

RESEARCH RESULTS

In analyzing the transcripts and the videotape, many patterns concerning the shape of molecules and misunderstanding of concepts were consistently found. Students didn't seem to have a clear idea of what effects molecular shape and why shape is important. The abstract idea of formulating two-dimensional pictures of molecules without really knowing how they truly appear in three-dimensions seemed very difficult and challenging for the students. The guidelines set forth in class and in previous classes set the stage for the students in attempting to complete the task of drawing Lewis structures and building molecular models. The following results were found to be consistent among the students interviewed:

Finding 1: There was an understanding of the octet rule and how it is used in determining the Lewis structure of elements. The general chemistry students used this rule in determining how to distribute electrons among the atoms within a molecule. Without prompting, the general chemistry students automatically identified the octet rule as a guideline in drawing the Lewis structure and they were able to define the rule clearly during the interview. When interviewing the professor and the other advanced chemistry students, there was also a clear understanding of the octet rule and how it plays into drawing the Lewis structure.

Finding 2: The general chemistry students do not have a clear understanding of what factors that effect the shape of a molecule. When first asked, "What effects shape?", the response usually given was, "I don't know." Many times the general chemistry students would only refer to the number of elements in the molecule as a basis of shape after further questioning. The factor of lone pairs effecting shape would only come into account with the prompting of the question, "Do lone pairs of electrons effect the shape?"

Finding 3: Although the general chemistry students identified lone pairs of electrons as a factor affecting shape, the reasoning behind this affirmative response wasn't clear. Many students identified the lone pairs as just a numerical factor in counting the number of species extending from the central atom in order to select the correct shape, without regard to how the electrons occupy the space. One advanced chemistry student didn't clearly understand how lone pairs effect shape, as well. The professor characterized the effect as, "...[electrons] are negatively charged and they will repel each other and try to get as far away from each other as they can i.e. minimize the repulsive energy. And this approximates the minimum shape."

Finding 4: The students didn't have a good idea of what kind of shape the molecule occupies. The analytical process of understanding how each atom occupies a certain space and how that effects the placement of the other atoms within a molecule wasn't achieved. Instead of knowing how each atom occupies space and therefore how the molecular geometry was generated, the students attempted to memorize the shape for each type of arrangement. When students encountered molecules which were unfamiliar to them, they often couldn't identify the shape. The response to the question, "How did you know to choose that shape?" was often "That's what I memorized from class." The advanced chemistry students didn't seem to know the names for particular shapes , but were able to occupy the space appropriately when building the molecular model. The professor was quite fluent in his building ability and was able to clearly identify shapes and names without a flaw.

Finding 5: The students don't really know why the shape of a molecule was important. Student would respond when asked, "Why is shape important?" with an answer that didn't truly answer the question or with the response, "I don't know." In order for this concept to have any value to the student beyond just an assignment in class, there should be an understanding of why it is important. Only one advanced chemistry student had trouble with this question. The other advanced chemistry students identified reactivity and bonding with other molecules as reasons. The professor cited examples in biochemistry focusing particularly on the function of isomers and indicated how shape determines taste and smell.

Finding 6: In determining the central atom, the only response given as to the selection of a certain atom was because there was only one atom of that element represented in the molecule. There was no mention of electronegativities, except with one student, but she had the concept confused. Instead of just giving the students a short cut on how to select the central atom, maybe the students need to know how to truly select the central atom in order to better make the connection between the why and how of molecular shape. The electronegativity was the only reason cited by the professor for the selection of the central atom.

In reviewing the findings of this project there are many aspects to student's perception of molecular shape. Some concepts made sense to the students, yet there was a missing link in their understanding of molecular shape. The students seemed to be moderately successful in completing the tasks of building molecular models and drawing Lewis structures, but there was not a clear understanding of why they were doing the what they are doing.

CHAPTER IV

IMPLICATIONS

The concepts of molecular structure and shape are complicated, in that, it isn't something that can be looked under a powerful microscope or be seen with the naked eye. Standard rules are used to build conceptual models and various other materials are used to build concrete models, yet they are still only models. In searching out the answer for why students are challenged in drawing two-dimensional Lewis structures and then building three-dimensional molecular models, many misconceptions were uncovered. The missing links in the chain of understanding were found to be in understanding what effects the shape of a molecule and why shape is important.

Through modification of instructional methods a better understanding of molecular structure and shape could be achieved by the students. There are students with many different types of learning styles. As a teacher, it is easy to get into a teaching mode of lecturing to the students most of the time and then expecting the students to read from a textbook or practice the concepts with a worksheet, but not allowing the students expand their understanding through discovery. Science is based on thousands of years of discovery and instruction needs to be designed to allow for discovery when it comes to learning complex and often challenging concepts. Students are likely to swiftly memorize information only to get through a particular unit or assignment without fully grasping the greater meaning and taking on many misconceptions.

In analyzing how to best address misconceptions, it is important to realize that every misconception cannot be identified and resolved. Through guided questioning and discovery activities, the teacher can identify many misconceptions. These misconceptions can be confronted by either addressing them directly or through discussion and guided activities.

As a teacher, there are instructional methods that could be altered to improve an understanding of molecular shape. First, the students need to discover the placement of atoms within a molecule before mentioning any specific shapes. The students should explore the arrangement of the atoms with respect to the lone pairs and discover why molecules form into specific geometries. These discovery activities could be done in small groups or individually. Providing manipulatives such as marshmallows and toothpicks to discover the placement of atoms prevents any predictability in bond angles that prefabricated model kits provide. After the understanding how atoms within a molecule occupy space, then the students could identify and name specific shapes.

Technology is such an important aspect in developing scientific knowledge and should be incorporated whenever possible. Utilizing a computer program that allows the student to build three-dimensional models where the manipulation of bond angles and rotation of the molecule viewed (easily done with a mouse) can enhance understanding of molecular shape and introduce students to another form of technology. The research conducted by Brady, Milbury-Steen, and Burmeister (1990) included the use of a computerized lesson on drawing Lewis structures. Including these various modes of media and others, such as laser discs, that break the two-dimensional barrier will only further a better understanding of this complex concept. Background information on molecular geometry, including the history of how shape was discovered, and why shape is important are other aspects that could make a difference in understanding these concepts better and integrating them into a coherent framework of chemical knowledge.

References

1. Brady, John A.; John N. Milbury-Steen; John L. Burmeister, Journal of Chemical Education, 1990, 67, 491-493.

Appendix

Research Transcriptions - Pilot Study

Student #1 - Luke Hale, Male June 17, 1997

I: Okay, um first, I want to explain this [consent form] piece of paper, here. What we need for you to do is to sign it, um, saying that you consent to going through with this research project. And, I'll go ahead and read it to you. It says, we are asking for your participation in a project that will...help us understand how students learn certain chemistry concepts and how instruction can be changed to improve student understanding. Your participation in this project will not affect you grade in the course. Thank you for your assistance. We appreciate that you are willing to take the time to participate in this project. And, what was your name again?

L: Luke Hale.

I: Hale..

L: H-A-L-E

I: All right,...

L: Do you want me to sign this?

I: Yep, that would be fabulous. Okay, the first thing that I have to ask you is, have you ever worked with Lewis Dot Structures before this class?

L: Yes,

I: Yes? Okay, um, next, what I am going to do is, I'm going to give you a series molecules and what I need for you to do is, um, I'll start with this one [H_2O] ...just water. What I need for you to do is to draw the Lewis structure for water.

L: Okay.

I: Just the Lewis Dot structure. And as you go through it, um, if you could can think of any rules that you used to apply, um...what you are thinking.

L: Oh, well, what do you mean, like talk while I'm doing it?

I: Uhh, yeah if you could...what you are thinking.

L: Well, basically, I just kind of do what, I don't know, basically what I am told. First, you know, I look for the central atom, or whatever. The one that has..that is the found the least of these...and since there is only one oxygen, I put that one in the middle. And for, you know, hydrogens on they are on both sides. So I look at...I make it look like its equal you know or proportionate or whatever.

I: Okay.

L: Um, and then I check out, you know after I write down the basic things, and then I check out, you know um, what each one [element] is. You know, oxygen has six valence electrons and um hydrogens each have one.

I: Okay.

L: So then I add that up that's a total of eight. So, eight, now I look at the ones are actually in there. And there's actually four in there [bonding electrons] so I subtract that.

I: Okay.

L: So there's four left [electrons] and then you just kind...you have to look at what you have there. And since hydrogens are...have like a, I don't know, ...they are not supposed to have more than two total. You know, um, then I don't add anymore to the outside there [the non-central atoms] But I still have to add two more sets of electrons, so the only other place that I can put them is on the inside [central atom]. So, I just kind of do that.

I: Okay.

L: Um, I don't know if that's right but...

I: Okay, good. Um, next what I need for you to do is to build this model using toothpicks and marshmallows. Um, so you can just use whatever you want to use...whichever sizes that you feel more comfortable with. And we have some wet wipes here if...because they [marshmallows] are kind of sticky.

I: Okay, all right, can you tell me what each of the marshmallows represent? And what the toothpicks represent?

L: Well, the..um originally H-2-O or water is actually a um..tri, no its a ...triagonal pyramid or something like that. It's supposed to have four. It's actually supposed to look like this.

L: And you get that because you look at...you look at your structure here. And you see that there's...you got basically, I count up how many, um, pairs of electrons that are around the central atom.

I: Okay.

L: And there's, you can see there's two that are bonded and then there's two, um, that are not bonded. So they are not there. Um, so you got really, its basically, what...I forget the name of the shape, its like a triagonal pyramid or something like that. Um, but anyway, and then you got to look, uh, but there's only two that are actually there, so basically you just kind of remove two of them. So you have, these are your bonds or whatever.

I: Okay.

L: This is your oxygen and these are your hydrogens. And it is a bent molecule.

I: Okay, um, that's very good. Um, what do you think causes the shape of a molecule?

L: Um, well, from my understanding, its the uh since electrons like you know like repels like or you know or whatever. Um electrons have a negative charge and since electrons they don't...aren't attracted to each other. They naturally repel each other. So when they are forming around a central atom or they, you know, repel each other to the point where, you know, like with this one [water] if there is only four points or whatever. The shape is caused because that's as far away as they can get with repelling each other.

I: Okay.

L: Before its, uh...I mean it can't go any further, so...

I: Okay, good. Um, why do you think shape is important?

L: Well, probably, it helps out because uh...I mean it...you know, I guess some of it is polarity or something like that, you know, just you know figuring out you know...like for instance, you know, you know it like an understanding of why water is this bent molecule. You know, well, without knowing like what kind of shapes and things that could actually have in there, you would never really know what that, I mean, for all you know it could be, you know, straight or uh ...so it just kind of helps with the, I guess knowing the...I don't know, knowing the charge of it, I..I really don't know exactly why.

I: Okay, that's fine. Um, when you're thinking about going from a Lewis Dot Structure to an actual three dimensional model, what kind of challenges did you face?

L: Like?

I: Building the molecule...the molecular structure.

L: Well, just basically, you know, you write down you Lewis Dot Structure, or whatever, when you write something down. Let's say something that's got like...you know, say this wasn't H-2-O, say it was you know H-5-O or something like that or O-H-5 or something like that. Well, when you write it down, you know, you'd be like...to do a Lewis Dot Structure I usually write it like this instead. You know, with five of them [hydrogens] coming off all equally or whatever. But that's not the actual shape, so, you know, remembering like what the shapes actually look like as compared to what you see on there [paper]. And, plus, too like things like you know um H-2-O you got these extra electrons on the outsides here that are just hanging around, well those actually make a difference in the shape. And, so you gotta remember, you know...

I: Okay, good. Um, let me go ahead and give you the next one. Here you go...and just go ahead and...

L: The same thing...Lewis Dot Structure.

I: Okay. Um, then again go ahead and build the molecular structure from the Lewis Dot Structure.

L: Okay,...

I: Is there any reason why you picked the bigger marshmallow than the...

L: It's just because it is easier to uh stick the toothpicks in there...

I: okay, okay...

L: ...than the little one..I don't know.

I: Okay, and can you tell me what each of the parts represent?

L: Okay, well this is the uh nitrogen atom in here, and then these are the three hydrogens. And just like before its like actually a whatever its called, a tetrahedral, or whatever its called. Um, but since one of them, 'cause you have extra pair here, but that pair is not bonded with anything, so that's up here. So its actually a pyramidal shape.

I: Okay. Um, lets see here...okay you said, what was the shape again?

L: I think its pyramidal, it what I think.

I: Okay, and how do the lone pair affect the shape?

L: This lone pair here? Well, because, uh, its still there and so it still has its charge. You know, um, but since its really not bonded to anything or whatever. Its not, you know, it doesn't...when you do the molecular thing, there's not actually not a molecule there. So, you can't show it. But, um, since its still, just like before, you know where its repelling...all repelling equally, it still needs to be there to you know...so, since its still there. It sends the other ones into their shapes, so...

I: Okay, I'll go ahead and give you the next one. Okay, and again, I need for you to do the Lewis Dot Structure first...

L: This is what I meant by like when I set it up.

I: Right, okay.

L: I don't know if all people do it like this, but...

I: And why did you choose, um, the phosphorous for the middle?

L: Because, just like before, I looked and there is five chlorine... molecules or atoms there, and there is one phosphorous, so I just kind of look at it as obvious. I guess.

I: Okay.

L: So, I figured out that there's...I took the total amount of uh valence electrons that all of them have and then I subtracted all of the, uh, bonds there because that's two each...so they equaled out to be thirty. I have got to put thirty in there.

I: Okay.

L: So, I start out...okay, I started out filling the outer ones first. And, then I ended up using them [electrons] all up. I just double checked on the inside and they...and supposed to fill the octet rule which is, you know, supposed to have eight. Phosphorous actually has ten in there, so uh, I'm okay with that.

I: Okay, um, next what I need for you to do is go ahead and build the...

L: Build this one?

I: Yep, build that one with the marshmallows and the toothpicks.

I: Okay, why did you place the, um, toothpicks in that arrangement?

L: Okay, well this is just mostly from memorization, actually, but if you...you can really sit and kind of picture it, um. You try and place all of them as, I guess, as far away as you can from each other. And geometrically, this is the way it is.

I: Okay, okay, and what does each part represent?

L: Well, all of the little colored ones [marshmallows] on the outside are the chlorines and this one is the phosphorous in the middle, here. And these [toothpicks] are the bonds.

I: Those are the bonds...okay. Um, lets see here, what is the shape of that molecule?

L: Um, if I can remember, this is a triagonal pyramid. I think, a triagonal pyramid.

I: Okay, all right, um, and I'll go ahead and give you this last one. And go ahead and do the Lewis Dot Structure.

L: Let's see here...these are always the ones that I usually don't do too well on, but...

I: What do you think makes it difficult?

L: Well, you see on this one, and this is the part...its kind of like, I guess it because of my background in this stuff. I've had teachers teach me different ways of doing this...this kind of thing. So, basically, the way I'm doing it now, I just learned yesterday or today.

I: Okay.

L: Um, but what makes it difficult is you have...you fill the outer, you know, the outer molecules here, whatever, with the octet rule..to fill the octet rule, you still have one left over. You still have one pair left over. Actually, so what you do is you got...I usually put the pair on the inside. See then you check, and there...the inside. Sulfur doesn't fit the octet rule, so what you have to do...or what you are told to do, what the rule says to do is to move, you know, the outer electrons. Move it around until you get a double bond. And you can do that just by easily moving an oxygen, you know, in here to get a double bond. That way you've got eight around here and you got eight here. And see, I don't know if you're allowed to have a double bond plus have this thing [lone pair] in here. But I guess, that's what...to me that, this is the way to do it.

I: Okay.

L: And you can either choose this side or this other side.

I: Okay...

L: And that would be it.

I: Um, what do the parts of the Lewis Dot Structure represent? What do each of the lines represent?

L: Well, each of these lines represent two electrons. Um, I could actually just fill in the dots here...two, two, two, two...and the ones in between here. I mean, its still two, but they're like bonding together, so like the sulfur shares this with the oxygen. And same here. So it actually, like, if you look at the octet rule, where each one is supposed to have eight surrounding them, this one shares these so this is four, six, eight,...and so on and so forth.

I: Okay, good. Um, then I need for you to go ahead and build the structure....they [marshmallows] are kind of sticky.

L: Yeah.

I: What do each of those represent? Those marshmallows?

L: Okay, well this is the sulfur and these are the oxygens in the bond. And again, there is a pair that's not bonded to anything..or attached to any molecules. So, that creates a bend in the molecule.

I: Okay, um, does the size of the marshmallows have anything to do with why you chose them?

L: Not really, you can really make it with whatever you want. Um, I'm sure, you know like, the size of the...oxygen..sulfur...the sulfur is actually bigger in size. You know, but just, we've also learned that...you know, how to decide how the size...You know, this is a little bit correct, but uh, I just chose it because it's easier to stick all the toothpicks in.

I: Okay, good. What kind of challenges in doing each of these did you find in when you had to go from a Lewis Dot structure to an actual three-dimensional structure?

L: Well, the only things, I mean, just like I was saying before...you just got to look at...like here, well I guess what can get confusing is you see like...these are four. There's two pairs here, so some people might consider that to be two...you know, I need to put two toothpicks in...I mean, one, two, three, four. When actually, you just got to consider, any time like an atom is bonded to another atom, you just count that as one. Like one toothpick or, you know, one line as far as when you're trying to draw these things, molecularly, or whatever. Um, and then you've got to remember to count that...the ones that aren't bonded to anything. Other than that, for me, its pretty easy. I guess I can see things that, as far as three dimensional, pretty easy. So it really doesn't...its just, you know, finding out how many little toothpicks you have to put in it.

I: Okay, what have you, um, learned in class or read in your textbook that has helped you to understand this better?

L: Understand this? You know, I don't know, I've always found that sometimes teachers try to teach too technical, or whatever. For me, I just kind of make up, not really make up rules, but simplify things a lot easier. Just, you know, and not really...I mean I understand why things happen, but I try not to think about...and justify every time I'm doing a problem, you know, why. So, basically, the only...I think the thing that helped me the most was just when, like, when we were doing the worksheets downstairs. Just like when I count these up, I just count how many bonds or whatever around the central atom. And I don't worry about, you know...well, this is a double bond but see if you look at the double bond...you know, I just kind of do it.

I: Okay, what prevents that [SO_2] from being linear?

L: This? Well, the same reason is like this one it has a pyramidal, or whatever. Um, there's still two more electrons up here in this molecule. Um, and because they are repelling each other, um, these can't stay linear, because they still have some room to go before these two repel each other. So, there's still two electrons here. I guess this can represent two electrons, but um there's no molecule with it. So, when you write it, its like this, its not linear.

I: Thank you...

Student #2 - Jamie Lang, Female June 17, 1997

I: Okay, um, first of all, this is a, um, a consent form and I'll go ahead and read it to you. Um, It says, we are asking for your participation in a project that will...help us understand how students learn chemistry concepts and how instruction can be changed to improve student understanding. Your participation in this project will not affect you grade in the course. Thank you for your assistance. We appreciate that you are willing to take the time to participate in this project. And, we need for you to sign that you are willing to participate. Right there...And what was your name?

J: Jamie Lang, J-A-M-I-E-L-A-N-G

I: Okay, okay, let me just go ahead and tell you a little about this project. Um, Dr. Towns told you that I'm a chemistry education major and I'm hoping to teach next fall. Um, this project is just an examination of the understanding between Lewis Dot Structures and Molecular Structures. I'm just going to ask you, um, to do a couple of things. First, um, I'll go ahead and start with the first one. What I need for you to do is to go ahead and draw the Lewis Dot Structure.

J: Okay.

I: And as you draw it [H_2O] if you could tell me maybe some of the rules that you are using...as you draw it.

J: Okay, um, oxygen is going to be the central atom. And, I'm finding the "O" on the Periodic Chart here, that oxygen is six electron...elec..right? Or..

I: Okay.

J: And then, uh, two hydrogens...that's eight. And since you've got two bonds here, you're going to have to subtract four. There's two, four, and you've got four here. And that means four valence elect...or lone pairs, I guess. And you add those to the central atom and...What else do you want me to...?

I: Okay, um, when you look at the Lewis Dot Structure, what do you get from it or what does it represent to you?

J: Its a tetrahedron, or tetrahedral...I can't say it right.

I: Okay, what I need for you to do next is to take the marshmallows and the toothpicks. And you can use any of them that you want and if you could build for me the water molecule.

J: Okay. It's kind of sticky...That's the oxygen. Well, actually, its going to be more or less like this. These are the two hydrogen, right here. I guess I should've made those different colors since they are two different chemicals. And then there is two, two lone pairs, I guess, and its a bent molecule.

I: Okay, okay, and why did you put the toothpicks like that?

J: Um, because...these right here, you mean?

I: Uh-uh.[yes]

J: Because they're, um, well, uh...these here are the hydrogens and these are the lone pairs. And its a bent molecule...a tetrahedron...that's the shape for it. It's something like that..it's hard for me to make...

I: Okay, and how did the lone pairs affect the shape?

J: Um, how did they affect the shape...hm, well, I guess I really don't...I know how they do because I do it all the time on these, but um, hmmm...Let me see. Well, they are not going to have...hmm...I don't know how to say it. But...let's see...I don't know.

I: Okay, that's fine. Um, why do you think that the shape of a molecule is important?

J: Why I think its important?

I: Uh-uh.[yes]

J: Um, well, its...I don't know really. I know there's...it makes me understand more about how, I don't know, the energy or whatever and stuff. Um, or not the energy, but that really ain't got nothing to do with that. But, um, because I wouldn't, before I ever learned that I always just thought well its just molecules, you know,...but, um, now that I understand like the structure, you know, you see things differently. I mean a water molecule, you know, you would...I always thought of it as just water, but now that I know this...I mean there is an actual shape there. It makes me look at things differently. You know...

I: Okay, before, um, this class have you ever worked with Lewis Dot Structures before?

J: Uh-uh, yes...in high school.

I: In high school...okay, um , what was...what was one the, um, challenges you faced when you had to go from a Lewis Dot Structure to an actual three dimensional molecule?

J: Umm...let's see...I picked up on that pretty fast. Like when I go to do it on paper, I , you know, picked up on that pretty fast. I just pretty much...I just understood. Its one of the easiest parts for me to understand as far as chemistry goes. Because I had a lot of practice in high school doing it, so my teacher...we did a lot of worksheets and practicing. After practicing, I learned how to do it. You know...but...

I: Okay, um, I have another one....let me get this out of the way....this is the next one. And I need for you to go ahead and do the Lewis Dot Structure. And if there is any rules that you are using, um, if you could tell me...as you draw it.

J: Okay, there's nitrogen and its the central atom.

I: Why did you chose nitrogen as your central atom?

J: Um, pretty much...just out of...there is a ...its got the highest or the...I guess the highest electronegativity. Is that what that has to do with it, the highest electronegativity?

I: I can't really answer that.

J: Okay, it's something like that...but, usually the one that's by itself like it, I just know like if there's one by itself it's going to be the one in the middle.

I: Okay.

J: Okay...that's five, three, and that's eight. So there's going to be...minus six...two. It's going to have a lone pair on it.

I: Okay.

J: Do you want me to build it?

I: Yes. Go ahead and build the structure.

J: It's tetrahedron also, because it's got four things coming off the central, central atom.

I: Okay.

J: And...

I: It's sticky...

J: That's okay...

I: Is there any reason why you chose the bigger one for the middle [nitrogen]?

J: Yeah, because its the central atom, or nitrogen. It's just the way I've always seen it.

I: Okay, tell me what each of the parts represent.

J: Um, this is the lone pair on the nitrogen. This is a hydrogen. That's a hydrogen and that's a hydrogen.

I: And what do the toothpicks represent?

J: The bonds.

I: Okay, um, does the lone pair there affect the shape of the molecule?

J: Uh-uh [yes] yeah, it does...let's see...the original shape is a tetrahedron, and since its not...its got the lone pair and has three things, I think its...oh what's that called...tri-...it makes a different shape. I can't remember it exactly what it is. Trigonal...something...

I: Okay. Um, let's see, what, um, what challenges did you face going from the Lewis Dot Structure to the three dimensional, or did you have any problems?

J: No. No problems.

I: We'll go ahead and move on to the next one. You'll have four total, just so you know. I'll go ahead and take this...and then you can go ahead and get started on the Lewis Dot Structure.

J: Okay...

I: How do you know how many electrons for each...

J: It's the number up here on each column. That's what I go by. There's seven on chlorine, and there's five chlorine, so I take that times five...actually it should be thirty-five. That's five and add that...forty. And I subtract for each of the bonds, there's two, four, six, eight, ten bonds so I subtract that and that leaves thirty electrons. So there's.... that's thirty all together.

I: When you look at that, can you tell me what the Lewis Dot Structure represents?

J: Yeah, its got to be a trigonal bipyramidal shape I believe. Because its got five things coming off the central atom.

I: Okay, you can go ahead and build the molecular structure.

J: Okay.

I: Why did you put those toothpicks straight across from each other versus at angles maybe?

J: Um, because its a 90 or its going to be at 90 degree angles...no actually, those two will be straight across from one another. Weird angles in these, I can't quite remember off hand what they were...but um....

I: And what do the small marshmallows represent?

J: The chlorines.

I: Okay, the large one?

J: Is the phosphorous...

I: Okay, and each of the toothpicks represent?

J: The bonds.

I: Okay, what causes that shape?

J: Um, what causes it? Oh, gosh I used to know all of this. Its been a while since I've been in chemistry since high school. But, I used to really know this good, um, let's see, I don't...I know that since there's five I just know that since five things come off, like right off hand right now, I know since five things come off the central atom its got to be trigonal bipyramidal or whatever that is...

I: Okay.

J: There's something else to it too. I can't quite remember what it is though.

I: Okay, um we'll go ahead and do the last one. And I'll take that one. There you go and go ahead and do the Lewis Dot Structure.

J: Okay.

I: What makes that different than the water molecule?

J: Uh, the water molecule?

I: Uh-uh [yes]

J: It's only got one set of lone pairs and the water molecule has two. So therefore the whole shape is going to be different of this one. Its going to be trigonal planar or something like that because...and the molecule is tetrahedron.

I: Okay, and um, how did you know how many to put around the oxygen and around the sulfur, how many dots?

J: Actually, you know what, I think I might have messed up on this. Because that is going to have to have an octet or four. Is that right? Or you can't tell me can you?

I: No, I'll just let you figure it out.

J: Let's see, okay, ...

I: What's confusing you or making this difficult?

J: Um, well the sulfur is supposed to have, I think, um , a filled outer shell like eight, an octet. So, um, I've done this a million times and I cannot think of how to do...okay. Um, I think this...you're probably going to think that I am crazy. Now, its got two double bonds, now whether that's right or...

I: Okay, um, go ahead and take the marshmallows and the toothpicks and go ahead and try to build the molecular structure.

J: That's not right...is it?

I: If you want to look at that still...if its not right.

J: I'm not really sure what it is....

I: So, its got just a single bond right there and then the double bond...

J: I think so...

I: Go ahead and build that. And what do each of those represent?

J: Um, this is...these two are oxygens. And this is a lone pair. If that's the right Lewis Structure I made there.

I: Okay, and what is that shape?

J: Um, trig...well, its a bent. No...this is a trigonal plane with the three things from its original shape and then with the lone pair...it'll be..um, let's see, I guess with the lone pair it'll be a bent molecule.

I: Okay, does the double bond affect the shape at all?

J: Um, I don't know. Well, the double bonds are shorter but they are stronger. I know that much. But, um, I don't know if it really affects the shape.

I: Does the lone pair affect the shape?

J: Yeah. Yeah it does.

I: Okay, um...

J: I think that is the wrong Lewis Structure, but okay, go ahead. I'm sorry.

I: That's okay. Um what challenges did you face um trying to go from a Lewis Dot Structure to the three dimensional structure?

J: Well, um, just like looking to see what comes off the central atom. And adding up usually, you know what the shape is going to be after that. Or you can add the multiple bonds or the amount, number of lone pairs, or the amount of single bonds or something like that. And that can tell you sometimes what the shape is.

I: Okay.

J: I've never done it that way before until we had a worksheet in the class here. But, we did something like that.

I: Okay, what has...what have you learned in class or read from your textbook that has really helped you to understand Lewis Dot Structures and Molecular structures?

J: Um, let's see, I learned a lot of it back in high school. And so this has been kind of a little bit of review for me, although I haven't um we just started on this again yesterday. And its the first time I've done it for like three or four years. But, um, three years anyways. So, um, I don't know...I remember a lot of it from high school just the review. But I haven't really studied it really hard just yet. You know, since we've started on it here. So...there hasn't really been any...its been a review for me so far.

I: Okay, is there anything else that you want to add about what you've learned in class or in lab today?

J: I thought that it was real inter... a real good idea to use the marsh...we used marshmallows today in there. I thought that was a real good idea because it kind of helps a little bit. Because its hard to visualize in your mind, you know, these shapes. I mean you can draw the Lewis Structure and stuff, but when you look at something three dimensionally its a lot...you understand it a lot more. So...

I: Thank you very much for your time.

Student #3 Sarah Kirsch, Female June 17, 1997

I: I'm going to video tape you. I'm going to go ahead and give you this [consent form]. This is our consent form. And I'll go ahead and read it to you, it says we are asking for your participation in a project that will...help us understand how students learn chemistry concepts and how instruction can be changed to improve student understanding. Your participation in this project will not affect you grade in the course. Thank you for your assistance. We appreciate that you are willing to take the time to participate in this project. And I just need for you to sign it. And your name was Sarah...and your last name?

S: Kirsch, K-I-R-S-C-H.

I: Okay, um, I'll explain what we're doing here. I am a chemistry education major and, um, this project is just an examination of how students do Lewis Dot Structures and Molecular structures, kind of what you just did in lab. Um, I'm going to ask you some questions and ask you to do some Lewis Dot Structures and to build some models. So, that's kind of what we are doing. And, the first one is water. And, if I could just have you go ahead and draw the Lewis Dot Structure and tell me what kind of rules that you are using, um, as you build that if you can remember.

S: O [oxygen] is the central atom.

I: Why did you choose "o"?

S: Because there is only one.

I: Okay.

S: And then take the two H's [hydrogens] off of that [oxygen]. Its just your basic structure. And then the O [oxygen] has six valence electrons and H's [hydrogen] each have one. And this is..which makes seven, or eight. And then you subtract the bonds which is four each and your put...you start on the outside with putting the extra four valence electrons and since those [hydrogens] are already completed, you put them on the oxygen.

I: Okay, what do each of the parts represent, what do each of the lines represent?

S: Each of the lines is a bond. A single bond with two electrons.

I: Okay. Next what I need for you to do is to take the marshmallows and the toothpicks and if you could build that molecule for me.

S: Okay. With like the lone electrons as....

I: And what do each of those [parts] represent?

S: These are the bonds with the marshmallows on them. They are going to be the two H's [hydrogens] and the O [oxygen] and these two represent the two single...

I: Okay, what shape is that?

S: It's a tetrahedral.

I: Okay. Um, do the lone pairs affect the shape?

S: Well, with the lone pairs it is tetrahedral. Without it, it is a bent shape.

I: Okay. Um, why do you think shape of a molecule is important?

S: That's a good question. I'm not really sure. I always just kind of guessed that maybe it has to do with the durability of it maybe, or how easy it is to break apart or put together.

I: Okay. Um, okay, did you choose, um, those size marshmallows for any particular reason?

S: Just the big one for the central elect... atom and then the small ones for the supporting roles.

I: Okay. Let me go ahead and give you the next one. I can go ahead and take this. Go ahead and start working on the Lewis Dot Structure and if you could tell me any of the rules that you are using and what you are doing along the way.

S: Okay, the N [nitrogen] for the central atom and then the three H's [hydrogens] on to the outer. The N [nitrogen] has five valence and the three H's [hydrogens] each have one.

I: How do you know how many valences they have?

S: According to the...using the periodic table. N [nitrogen] is five and H [hydrogen] is one. Um, then there is the electrons used in bonding. Which leaves two left over. And since the H [hydrogen] is already filled, you put the extra two in the N [nitrogen] which also filled...fills that shell.

I: Okay, um, when you look at that Lewis Dot Structure, um, what can you tell me about the molecule?

S: Well, its got three single bonds and the lone electrons, two lone electrons on it.

I: Okay, good, um, go ahead and build the model using the marshmallows and toothpicks if you could. And there are some wet towels, there, if you need to wipe off you fingers.

S: There's four that need to be...four bonds represented. I'm going to make the tetrahedral structure with the toothpicks. And there's one set of lone electrons, so I'll leave one alone. And then I'll put the three H's [hydrogens] on the ends.

I: Is there any reason why you put the toothpicks in that arrangement?

S: Um, well that's the arrangement we learned today for the four.

I: Okay, good, um, let's see, do the lone pairs...does the lone pair of electrons on that affect the shape?

S: Um, yeah, with the lone pair not showing it is a pyramidal shape. With...if there was one showing it would be tetrahedral, but there's just three bonds here it'll be pyramidal.

I: Okay, good, we'll go ahead and give you the next one. Okay, if you could just go ahead and do the Lewis Dot Structure.

S: With P [phosphorous] in the middle, again because its the central atom. And then bonded with each chlorine. The chlorines each have seven valence electrons and there's five. And the P [phosphorous] has...five. Which makes forty in all. Then you subtracting these ten for the bonds and you get thirty. And you have thirty to distribute, so you start filling up the outside ones [chlorines]. There should be two, four, six, eight, ten, twelve, fourteen, sixteen, eighteen, twenty, twenty-two, twenty-four, twenty-six, twenty-eight, thirty. And you've used all of your extra electrons filling these shells which...go back in the middle.

I: Okay, um, if you could go ahead build the molecular structure with the marshmallows and the toothpicks.

S: Okay, I'm going to go ahead and make the...use the toothpicks to make the...the...ahh...I can't remember what it's called...bipyramidal, triangular bipyramidal or something like that. I can't remember...

I: Okay.

S: ...what exactly it is. And for...and the toothpicks represent all the bonds. And then, since there is no lone electrons then I'll put marshmallows on all of them [toothpicks].

I: Okay, is there any particular reason why you chose that arrangement to put them [toothpicks] in?

S: Again, that's how we learned how to put those like when you've got five bonds. You arrange them in this order.

I: Okay, good, um, let's see here. Okay, we'll go ahead and do the last one. And, if you could go ahead and get started on the Lewis Dot Structure.

S: S [sulfur] is the central atom, again. And the O's [oxygens] go on each side. The O's [oxygens] have a valence of six. S [sulfur] has a valence of six also. Which is a total of eighteen minus the four used in the basic bond. It will leave fourteen left to distribute. Starting with the end will be two, four, six, eight, ten, and twelve. And those are filled and so you put the last one here in the central atom. And since the central atom isn't filled, filled yet and its not beryllium or in period three, you have to make a multiple bond with one of the oxygens. So, I'll make it right there. Now, they are all filled.

I: Okay, um, why do start with the oxygen instead of starting with the sulfur when you are distributing the electrons?

S: Because, there you start distributing from the outside.

I: Okay, okay, and what do each of those lines represent?

S: This is the single bond, the multiple bond, and the lone electrons.

I: Okay, um, if you could go ahead and build the molecule with the marshmallows and toothpicks.

S: Okay. This is the central atom. And, since a multiple bond is only represented by one toothpick, I'll put it in the tra-...triangonal planar structure with the bonds you need to represent. And then putting the marshmallows onto the O's [oxygens] makes it a bent structure.

I: Okay. And does the lone pair on the central atom affect the shape of that molecule?

S: Um, well the, if it was bonded to something it would be the triagonal planar, but since its not, it just makes it a bent...bent structure.

I: Okay, let's see here, why do you think the shape of that molecule is important?

S: I don't know.

I: Okay, okay, um, in looking at each of these, um, structures going from the Lewis Dot Structure to the actual molecular structure, um, what kind of challenges did you face? What made it difficult?

S: Remem...really remembering what order the molecules are supposed to look like. And remembering that the double bond isn't two [toothpicks], its just represented by one toothpick.

I: Okay, what makes that [SO_2] bent instead of linear?

S: The two bonds are down and if it was linear it would be straight across from each other. And they are bent down.

I: Um, alright, um, in thinking about what you learned through class lecture, through lab, or from reading the text book, what has helped you in understanding, um, molecular structures and Lewis Dot Structures?

S: Mostly, the explanations that she gives during class. She works a lot of them on the board and then she'll give us worksheets. And any questions that we have, we can ask her in the class. She gives us a chance to do them in class.

I: So that's really helped you?

S: Yeah, a lot.

I: Is there anything else that you want to add?

S: I can't think of anything.

I: Okay, well, thank you very much for your time.

Student #4 - Jason Sherard, Male June 17, 1997
I: Okay, um, this piece of paper in front of you is a consent form. Um, I'll go ahead and read it and then I'll need for you to sign it. Okay, it says, we are asking for your participation in a project that will...help us understand how students learn chemistry concepts and how instruction can be changed to improve student understanding. Your participation in this project will not affect you grade in the course. Thank you for your assistance. We appreciate that you are willing to take the time to participate in this project. And I'll need for you to sign this. And what was your name...Jason....

J: Jason Sherard, S-H-E-R-A-R-D

I: Okay, great. Okay, um, I'm a chemistry education major and this is my research project. I am exploring, um, the understanding of Lewis Dot Structures and molecular structures. Um, I'm going to ask you to draw some Lewis Dot Structures and also put together some molecular structures, um, using marshmallows and toothpicks. And I'll ask you some questions along the way. Um, the first question that I have for you is, have you ever worked with Lewis Dot Structures before this class?

J: I have worked with them some in high school chemistry, so...I mean just kind of an overview of it.

I: Right, okay, um, I can go ahead and take this from you. And you can go ahead and get started, um. What I would like for you to do is if you could go ahead and, um, draw the Lewis Dot Structure and if you could tell me what you are thinking about as you do it, maybe some rules that you are using and that you remember.

J: In class, she us a set of rules and I kind of just kind of do an overview of those when I do it. First I look of course at the, you know, the number to tell whether, you know,...to tell how many molecules or...are going to be. With hydrogen, you know, there is seven electrons. You know, I multiply it by two...fourteen, plus six which is oxygen, so its going to come out to twenty. From then I just, you know, then I worry about lining them up. I know there's one oxygen and two hydrogens. So, I kind of....like that. And then I, you know, distribute the...and then after I do that, I check to make sure they follow the octet rule or the, well I just messed up actually, or the duet rule. Sometimes I make...like that, that's why I double check myself. Okay...its the camera doing this to me.

I: I'm sorry.

J: Hey that's okay. Um...

I: And why did you chose eight instead of twenty?

J: Because there is six and then the hydrogens there is one. I know...

I: Okay...

J: I don't know where that came from actually. Okay, that looks a little better.

I: Okay, good, when you look at the Lewis Dot Structure, what can you tell just by looking at it? What does it represent?

J: Well, it represents, you know, with this...the molecules it represents, you know, um, how many electrons are there in relation to the hydrogen and oxygen.

I: Okay, um, next what I need for you to do is to take the marshmallows and the toothpicks and see if you can build that, um, molecule for me using which ever marshmallows and toothpicks you'd like.

J: Okay...this one...do you want?

I: Yeah.

J: Do you want it to be the ele...do you want the molecular?

I: ...structure, yeah. Okay, what are those? What do those represent?

J: They represent the bonds between the oxygen and the hydrogen.

I: Okay.

J: These represent the hydrogens. And the big marshmallow represents the oxygen.

I: Okay, um, let's see here. Okay, from going from the Lewis Dot Structure to the actual building the molecule, um, what kind of, um, things did you have to think about? What made it different?

J: Well, I mean I just thought about, you know, how it goes together. I mean its kind of straight forward since this is linear. So, I mean I really didn't have to do too much, besides know that it is linear and put it together.

I: Okay, um, how did you know its linear?

J: Well, um, from class.

I: From class, okay. Good, um, we have four of these total that we are going to have you do, just so you know ahead of time. And we'll go ahead and do the next one. I can take your model and put it off to the side and get it out of your way. And I'd like for you to do the same thing, start out with the Lewis Dot Structure and if you could tell me what you're doing as you do it.

J: Okay, same thing, you know start out, hopefully I'll do this one right from the beginning. Um, you know, this one has...nitrogen has five and I add that to...one for each hydrogen, so I just add that...to three, which is eight. Okay, and then what I do is I line them up again. And when I do the Lewis Dot, I don't really worry about the particular order as long as they are all there, you know. You know, in the...around it....the hydrogens are around the nitrogen, there's six bonding. So then I just, you know, put two there so that I know that the nitrogen goes to the octet rule. The hydrogens go to the duet rule.

I: Okay, why did you pick nitrogen to go into the middle [central atom]?

J: Well, because there is only one.

I: Okay, um, go ahead and take the marshmallows and the toothpicks and see if you can't build that model for me. And tell me what you are doing while...

J: Okay. This one is a tetrahedron because it has, you know, four...I can't remember the word.

I: That's okay. Just do the best that you can.

J: But, uh, but I know its a tetrahedron because there are, you know, four sets of electrons around the nitrogen. So, I'm going to do that. I think...its going to be different than what's off the paper...Okay...then take one away. It's going to be a pyramid. I'm just kind of...what I'm doing...

I: Okay. What do each of those represent?

J: These represent the bonds and the marshmallows represent the hydrogens and the nitrogen. Of course, the big marshmallow being the nitrogen. This is suppose to be a pyramid.

I: Okay. What causes that shape?

J: Um, by uh...well this is a tetrahedron, but there's only three hydrogens and there's one, I guess, lone pair. So, you know, you wouldn't include that so it would cause, cause it to be a pyramid.

I: Okay, does the lone pair affect the shape of the molecule at all?

J: Uh, the shape of the...it does, it does. It changes it.

I: Okay, do you know how it changes it?

J: Outside of the...you said how does the electrons...

I: ... the lone pairs, yes.

J: Lone pairs, oh yeah, the lone pair. I don't know if it changes it...it just alters it. You know, just the way...I mean there isn't going to be anything bound to it, so its just not going to. At least the way it looks on paper its not going to be any.

I: Okay, good, um, did the size of the molecules did you choose...for the marshmallows, does that represent anything? Or did you just...

J: Well we done this part in class, and you know, for the central, uh, atom we used the big marshmallow. And so, for the ones around it we used the small.

I: Okay, um, let's go ahead and give you the next one. And I'll go ahead and take you model. And if you could go ahead and draw the Lewis Dot Structure and tell me what you're thinking.

J: Okay, again, you know, I'm looking at the number, you know, that coincides with the element. So its going to be, you know, five for...double check....

I: Okay, where did you get forty?

J: Okay, um, I took the chloride or chlorine times, you know, this five here times seven which is thirty-five. And then, this is five and then...so its forty.

I: Okay. Why did you choose P [phosphorous] to be in the middle [central atom]?

J: Again, because there is only one.

I: Okay. What are those lines around the chlorine?

J: Those represent, you know, the electrons. Electron pairs.

I: Okay, how did you determine how many to put around?

J: Well, right now, I'm just trying to follow the octet rule, so I mean...and so that works.

I: Okay. Looking at the Lewis Dot Structure, what can you tell me about it? About that compound?

J: Okay, uh, I mean...specifically? What do you mean?

I: Just anything...anything that you can think of when you look at the Lewis Dot Structure. Um, what do the parts...what does the Lewis Dot Structure mean to you? What does it tell you?

J: Well, it tells me that um, there are, um, in this particular molecule, has uh, you know...the chloride has this balance because it has eight electrons around it. And, um, this it doesn't have all eight...I mean it has ten electrons which is, you know, sometimes it can't...the octet rule is broken.

I: Okay, um go ahead and take the marshmallows and see if you can't, um, build that compound for me.

J: Okay. This is the tri-, triangular bipyramidal. I think that is how its pronounced.

I: How do you know what the structures are?

J: Well, I do it...all I really do is just count the bonding electrons. So, it has five so I know that's going to make it...

I: Okay. What are those?

J: These are the, uh, mole...electrons that are binding the chlorides to the...what is this?

I: Phosphorous.

J:...phosphorous...

I: What are the small ones?

J: The small ones represent the chlorides. And the big one represents the potassium...phosphorous.

I: That's okay. Is there any reason why you put the bonds in that certain way?

J: Actually, I was trying to, um, follow the just the diagrams that we had in class. You know, I know that these are supposed to be linear and this one is...in the background and this one is in the foreground. You know, ...my lack of artistic ability. That's what I tried to do.

I: Okay. Um, why do you think that shape of the molecule is important?

J: Well, um, I think that it has something to do with the way it bonds with other molecules or reacts with substances around it. So...

I: Okay, um, alright. And we have this last one. I can take that for you. And if you could go ahead and do the Lewis Dot Structure for that and tell me what you're doing.

J: All right, again, I'm matching up the element with the number. So, there's six for sulfur and oxygen has six also. This is times two which is going to be eighteen. Sulfur is the central and two oxygens on the outside. I always, I mean the way I do it, is just kind of just, you know, use...don't... try to follow the octet rule, but I kind of work backwards from there if it doesn't work. So, that's five and add two more...well, subtract. I'll need a double bond.

I: Okay, why did you do that?

J: I made it a double bond because the sulfur didn't follow the octet rule.

I: Okay. Um, go ahead and take the marshmallows and the toothpicks and see if you can't build that model for me.

J: Okay. I'll make it linear...no, yeah, it's going to be linear. But, yeah.

I: And what do those represent?

J: Maybe not, maybe its going to be a bond...what's it called? I can't remember. I know what it looks like.

I: Okay, show me what it looks like. Okay, and what do each of the parts represent?

J: Um, this is the central atom, the sulfur. And then the two smaller marshmallows are the oxygens. And these are the bonds between them.

I: Okay, why does it have that shape?

J: Because that's how its supposed to look. I wish I knew more and had more insight on it.

I: Okay. That's fine. Um, do you think the lone pairs affect the shape?

J: The lone pairs?

I: The lone pairs on the sulfur.

J: Yes, they do. Well,...

I: Do you know why?

J:...they do because if there wasn't a lone pair then it would be another, you know, probably another oxygen or something else it would bound to.

I: Okay, um, what, uh, challenges did you have when you were trying to go from a Lewis Dot Structure to an actual three dimensional structure? What problems did you run into?

J: Well, a lot of it, some of it is, you know, coming up with the right shape. You know, again, I've been over it, you know, very vaguely in high school. So it just, you know, this is the first time that we've had it. You know, we haven't...we just got to the chapter today and learned about it. So, its kind of all new to us and we're learning and going....learning as we go kind of. Just thinking through the procedure and making sure that you are doing it right. Checking and double checking myself.

I: Okay, um what have you learned, um, heard in class or read in your textbook that has helped you understand?

J: Well, I think, you know, doing this kind of stuff, you know. So you can kind of see visually and then I think the lectures kind of help because she kind of takes us through the process and explains a little bit better what is happening when we are doing what we're doing.

I: Okay, um do you have anything else that you want add about these structures?

J: Well, no. They are kind of fun, I guess.

I: No? Well, that's it. Thank you very much for your time.

Research Transcriptions - Fall

Student #1 - Matthew, Male, December 3, 1997

I: Okay, this is the consent form and it says, "We are asking for your participation in a project that will help us understand how students learn certain chemistry concepts and how instruction can be changed to improve student understanding. Your participation in this project will not affect your grade in the course. Thank you for your assistance. We appreciate that you are willing to take the time to participate in this project. "

M: Okay.

I: Okay, let me go ahead and have you state your...or ...give you a pencil and you can sign that [release form] if you would. Okay, I will go ahead and take that [release form]. Okay, what we are going to do and I'll explain it. [There are] four different, um, sets of structures. And what I'm wanting you...what I need for you to do is to draw the Lewis structure. And then I need for you to, there's some marshmallows over there and toothpicks, and I need you to build the shape.

M: Okay.

I: And I'll be asking questions along the way. Here's a periodic table if you need those. Um, let me ask...if you could tell me what you're thinking.

M: [Drawing the Lewis Structure of H_2O] Do I need to draw out the shape?

I: No, you can just draw it how ever you feel comfortable. And if you could tell what rules you are using. If you can recall.

M: Well, you know that central atoms normally have to have an octet. They obey the octet rules. And then you know that oxygens are central atoms. And hydrogens only has one electron to give so you never put lone pairs on hydrogens.

I: Okay.

M: So then you know that you have oxygen has six valence electrons, hydrogen has one. So there is two of them and that's eight. So you need eight, so you need two lone pairs around that [oxygen]. And that's going to be, um, tetrahedral.

I: Okay.

M: It's kind of hard [to build structures] with toothpicks.

I: There is also pretzels if you think that they will be any easier.

M: [Building the structures] No...yeah...I don't know how to do it with marshmallows.

I: Are you having the marshmallows represent anything?

M: Yeah, the electrons around the central atom. I'd say that's how you would do it. But I mean you don't have...it wouldn't look like that in like three dimensions. It would be like...I don't know...it would look like this, I can draw it for you. You have oxygen as your central atom. And you have one [hydrogen] here and one here. And then you would have two lone pairs like that. [drawing]

I: Okay, what kind of shape would it take on?

M: Bent...or...yeah, bent. Wouldn't it be? Because you have one central atom...two...and then two. Either that or it's going to be linear. I'm not sure. I think its bent though.

I: Okay. What affects shape of a molecule?

M: Um, like what...how many uh bonds are around it and then lone pairs.

I: Okay. Do the lone pairs...how do the lone pairs affect shape?

M: Because they repel, or whatever, like they make them. Like since electrons don't like each other they like want to go farther apart. And if there's lone pairs actually they push them [other atoms] closer together cause they have like uh repulsion type of thing.

I: Okay.

M: I don't know. I'm just babbling away.

I: That's okay. Um, why is shape important?

M: Why is shape important? I don't know.

I: Okay.

M: I have no idea what...why it matters what shape it is.

I: Okay.

M: I guess it is just to give you an idea of what it looks like in three dimensions. Just to make you, probably help you understand them better.

I: Okay. Um, if you would go ahead and do the second one [SO_3^{-2}]. That was "H-2-O" and this is "S-O-3".

M: ...minus 2.

I: Minus 2.

M: Okay, oxygen has six [valence electrons] so that's eighteen. And sulfur's, what, six [valence electrons] also. So twenty four, twenty six. And you have sulfur in the middle.[Drawing the Lewis structure]....I need ten more [electrons] no I need two more, right?

I: Count them up.

M: [Counting] So its going to be tetrahedral again. And it has one lone pair. So...it is a "A-B-3-E-1" And its going to look like this [drawing]. Sulfur and oxygen...

I: See if you can try using the marshmallows. It might help if you use one of the marshmallows as the central atom.

M: One of them as the central atom? So if this is central...then you have it like that and like this [building the molecule]. This would represent your lone pair and then you'd have three atoms. With this [marshmallow] representing the lone pair.

I: Okay.

M: And then three molecules. But it would be more like...all wacky in three dimensions [adjusting the shape].

I: Like that..okay. Why did you chose that shape?

M: Because if it was...okay...they're going to want to repel, like, because negative..or, uh, like charges repel. And then because this one is at the top, it [lone pairs] pushes them, like, down and its tetrahedral shape.

I: Okay...

M: But, you could also do it like this. And the lone pair could be here [rearranging shape]...

I: Okay.

M: all right "C-O-3"?

I: "C-O-3".

M: Carbons are center. Carbon has four [valence electrons] and oxygen has six...[counting] eighteen, twenty two, twenty four.

I: Why did you choose carbon as your central atom?

M: Um, carbon is always the central atom...well, usually, generally...

I: Okay.

M: And then, plus, you know you have three oxygens so oxygen is not going to be your central atom 'cause you know that you are going to put those [oxygens] around it [carbon].

I: Okay.

M: ...around the carbon chain. And if it said "C-6-O-6" you know that you still have a carbon chain and you put the oxygens around it...[placing electrons and drawing structure]

I: What are you doing now?

M: Drawing the Lewis Structure. Um, put the oxygens around them [carbon] and then add your lone pairs around your oxygens to give oxygen and carbon both octets. They both need octets to fill the octet rule.

I: Okay.

M: So you have sixteen...eight, sixteen, twenty four...okay, well, you'll need, um, you have too many, so carbon has to have an octet. So, you have to make one of these [lone pairs] a double bond. It doesn't matter [which bond] because its in resonance bond.

I: Okay.

M: So, you have eight around your carbon and then you have...two, four, six, eight, ten, twelve, fourteen, sixteen, eighteen, twenty, twenty two, twenty four. Then you have an octet around all of them.

I: Okay....

M: This is a trigonal planar.

I: Okay, how did you know that was what it was?

M: 'Cause you have a one central atom and then you have three around it.

I: Okay.

M: So it has the...its hybridization is what..."s-p-2"? And then its other one is "A-B-3" for its molecular geometry.

I: Okay. Build that for me.

M: [Building the model] I have to have one of these as two toothpicks don't I?

I: Does the double bond affect the shape at all?

M: No. It shouldn't.

I: Okay.

M: That represents your double bond...two sets of electrons sharing with one of the oxygens. And the middle marshmallow being the carbon.

I: Okay. Good. Okay, if you could do the last one [XeF_2].

M: "x-e" that has eight [valence electrons] and fourteen ...that is twenty two. Your fluorine is going to go around your central atom, Xenon. That gives you sixteen, eighteen, twenty, twenty two. Okay, Xenon doesn't have to follow the octet rule because it has eight valence electrons. So it can have more than four...it can have more than an octet.

I: Okay.

M: Um, so, you have...you have to make fluorine have an octet on the outside. And then whatever lone pairs you have left over, you add to your central atom. so you have sixteen here and then that leaves you with six electrons so you put them on Xenon. Um, the...that would be, uh, the molecular one is uh...let's see.. "A-B-2"...its trigonal bipyramidal. But I don't know, what, I think its linear or bent maybe. I think that's what the correct name for it is.

I: Okay.

M: [building the model]...I don't know really what it looks like in three dimensions. [Thinking]...there's three lone pairs...let's see its trigonal...something like that.

I: Okay. Why did you choose that shape? Having those straight or having those in a different arrangement [the marshmallows]?

M: Well, I tried to put it in three dimensions. I don't know, using marshmallows. Cause you have, I'd say it [angles of marshmallows] would be more down like this. And these might be farther apart, but with the lone pair at the top...these two on the side..and then these two are your fluorines.

I: How did the lone pairs on that central atom affect the shape?

M: Um, I think this one [on top] up here would push these two closer together. But these...I don't know. I don't understand all of that about the...how they make the shape. I just know that they don't want to be closer together because they are not attracted to one another because they are different charges. So you want to get them as far apart as you can. So I took that...'cause they all look..

I: So, in your experience with your chemistry, what has helped you the most, whether it be in class, lecture, or in lab that has helped you understand this concept the most?

M: The concept of this? Um, I'd say lab probably the most because it is hands-on. You get to build the structures and then you get to look at it and say, 'oh well now I kind of understand why it looks like this.' And they give so many different problems that I mean...you have so much practice at it that you should be able to remember it. And I mean when you...some people when you are giving a lecture, its hard for them to picture in their head what you are trying to say. And I think that the lab allows you to look at it and have a better understanding.

I: Good. What do you think helped you go from a Lewis Dot Structure to a model? What kind of thinking did you have to use? What kind of,um, things did you think about?

M: Basically, thinking about that you know that the electrons are not going to attracted to one another. I mean, that's the biggest thing. And you know that when you build a three dimensional shape you have to think about how things are going to come together to make it, like, what's the word I'm looking for, congruent maybe, or equal throughout. Because you know that two of them are not going to be real close together and the other three are going to be spread or whatever. You know that they have to be kind of equal all about. So that's what helps you build the structure.

I: Okay, what has been one of the biggest challenges been in doing this?

M: Building the structures...finding out what the shape is. I mean.. this right here...not the best...its just really hard to get a picture in your mind of what, what the atom actually looks like.

I: Okay.

M:...or what the molecule actually looks like.

I: Okay, is there anything else you would like to add?

M: I don't think so.

I: Okay, well thank you so much for your time.

Student #2 - Christina, Female, December 3, 1997

I: Okay, this is the consent form and it says, "We are asking for your participation in a project that will help us understand how students learn certain chemistry concepts and how instruction can be changed to improve student understanding. Your participation in this project will not affect your grade in the course. Thank you for your assistance. We appreciate that you are willing to take the time to participate in this project. "

C: I have filled out one of these for Psychology [class experiments].

I: Okay, what I'm going to do is that I'm going to give you four different, um, compounds and what I need for you to do it to draw the Lewis Dot Structure. Tell me as much as you can about what you are thinking when you are drawing the Lewis Dot Structure or the rules that you are using. Anything that you are thinking about and then I will have you build the geometry with marshmallows and toothpicks.

C: ...[laughing] all right!

I: Let's go ahead and get started with H-2-O.

C: Okay...H only has one [valence electron] so that makes two. O [oxygen] is the central atom.

I: Okay, how did you select O [oxygen[as the central atom?

C: Because it has the least amount.

I: Okay.

C: So...I don't know how to do this! Of course, I'm under pressure so I'll go blank.

I: Just relax.

C: ...these are probably really easy too.

I: What number do you use for O [oxygen] when you are doing a Lewis Dot Structure?

C: That's what I'm forgetting! Gosh...thank you.

I: You're welcome.

C: ...[counting and distributing electrons]...there we go!

I: Okay, what shape is that?

C: Um, I don't know the names. Of what we just learned? I don't know those names.

I: Um, could go ahead and try to build the model using marshmallows and toothpicks?

C: Let me write it out first. [counting] Isn't it two words the "four one"? I don't know. I'm only getting confused.

I: Don't confuse yourself.

C: That was....[drawing] I didn't do a whole lot of building with these [during lab class].

I: Are you representing each atom ? Each element with each of the marshmallows? Is that what you are doing? Is that how you are building it? Is each marshmallow represents an element?

C: Uh-huh. Yeah.

I: Okay.

C: Is that what you mean? With the marshmallows there?

I: Sure.

C: I don't know what you mean by drawing them...

I: Just building the model...kind of like what you did in lab, but with marshmallows and toothpicks. Okay?

C: Is that what you mean?

I: Yeah.

C: Okay.

I: Are the yellow ones the hydrogens?

C: Yeah; the yellow ones are the hydrogens. And the pink is the oxygen.

I: Why did you choose that shape instead of having them linear? Why is it bent?

C: I don't know.

I: Okay.

C: I don't know, I just did it.

I: Okay do you think the lone pairs had anything to do with it?

C: Probably. The way I had them. I don't do a lot of the straight up and down. I get confused with the double bonds than if I do it that way.

I: Okay. That's fine. Um, what do you think causes the shape of a molecule?

C: Causes the shape of the molecule....the way I did it or like the way it should be?

I: Either.

C: I don't understand this question.

I: Oh, okay, what do you think causes the shape of the molecule...what you just put together to be that way versus any other way? What causes the shape?

C: What causes it to be like this [moving shape]?

I: Yeah, or instead maybe in ....zig zags, for example.

C: Because its an even number, you have to have an octet. It just makes it look nicer.

I: Okay, we'll go ahead and go into the next one. S-O-3 And if you could do the same...yes with a negative two charge.

C: Say what I'm thinking?

I: Yeah, the same thing.

C: [counting]....then you add two, right? Is that how you do it?....[counting] You add two don't we, since it is a negative?

I: Just go ahead and write whatever you think. You are not going to get a grade on this or anything like that.

C: I know but....

I: We're more interested in how you think about it.

C: ....[thinking]....

I: Why did you select "S" [sulfur] as your central atom?

C: Because its the least amount.

I: Okay.

C: Oh, there's another "O" [oxygen]. That could help [in distributing electrons].

I: So you're subtracting...how much are you subtracting?

C: Six.

I: Okay.

C: [counting and drawing].....

I: Okay, what are you doing now?

C: I'm doing the dot thing.

I: Okay.

C: Because everything has to have an octet and there's twenty left. That's eighteen..did I do it right?

I: Okay, go ahead and build it. Do kind of the same thing with the marshmallows and toothpicks.

C: ...[building]...

I: Okay, why did you select that shape?

C: It just looks nice.

I: Okay. Um, is there any reason why, um, why the molecules there are linear instead of bent? Any reasons.

C: Well, because you have to have an octet. And then there's this other one....or I would have had to have one there. It just makes it look even.

I: Okay, all right. Let's go to the next one. C-O-3. with a negative two charge.

C: [drawing the Lewis Dot Structure]...I chose "C" [as the central atom] because its the least amount.

I: Okay.

C: And then subtracting the amount for the bonds....[counting and distributing electrons]...and then I gave it a double bond.

I: Why did you give it a double bond?

C: Because, they are going to have to share because they don't have enough [electrons] to give everything an octet.

I: Okay, why did you choose that particular oxygen for the double bond?

C: That's just the way I started and I just went clockwise.

I: Okay. What do Lewis Dot Structures mean to you? What do they represent?

C: Where all of the valence electrons go.

I: Okay, if you could go ahead and build the model. You don't have to use the same marshmallows, you can use new ones if you want. Don't feel like you have to recycle them.

C: Just a habit I have I guess. Isn't it the same way, or would I have one here? I have never done double bond structures I guess.

I: Okay, its up to you. If you want it to or not...

C: I'll use two toothpicks for the double bond.

I: Okay, does that affect its shape at all, the double bonds?

C: Not really, they just add an additional toothpick.

I: Okay, um, why did you choose that shape?

C: Um, the same reason. I just...its just the way I did it. I would rather have, I don't know....

I: Okay, that's fine. What is the shape of the molecule?

C: What do you mean?

I: Do you know what it's called? No?

C: No.

I: Okay, let's go ahead and do the last one. "XeF_2"

C: ...[drawing and counting]...I added up the electrons. And I am choosing "Xe" as the central atom because its the least amount. I am subtracting the bonds. And I'm adding the dots, [counting] and then Xenon is in the last period, so it can have extra electrons.

I: Okay. Um, if you could go ahead and build the model.

C: ...[building the model]...there you go.

I: What does the pink marshmallow represent?

C: Xenon.

I: And the yellow?

C: Fluorine.

I: Okay, do those lone pairs [on the central atom] affect the shape at all?

C: I don't think so.

I: Okay, why did you choose those [fluorine] to be bent versus being straight across, linear?

C: Well for the same reason, I just go in clockwise....when I start adding stuff.

I: Okay. All right. I just want to ask you a couple of questions. Um, have you ever had Lewis Dot Structures before this class?

C: Yes.

I: In high school? Just one year?

C: Yeah.

I: Okay, what have you learned from this class, CHEM 111, in lab or in your book, or from high school that has helped you to understand this concept?

C: Just all of the rules....lab helped. Like we had to do them a lot, and lab helped to understand. I don't understand lecture a lot, but the lab actually doing it helped a lot. Actually seeing and doing it helped me understand.

I: Okay, good, um, is there anything else that you would like to add? Well, thank you for your time.

Student #3 - Gary, Male, December 4, 1997

I: Um, I'll need you to fill out the consent form. It says," We are asking for your participation in a project that will help us understand how students learn certain chemistry concepts and how instruction can be changed to improve student understanding. Your participation in this project will not affect your grade in the course. Thank you for your assistance. We appreciate that you are willing to take the time to participate in this project." If you could sign that. Just a little bit about myself, I'm a chemistry education major. I plan to teach high school chemistry. And, this is part of my honors thesis that I'm trying to finish. And, um, what we will do is I have four different structures. And, what I would like for you to do is to write the Lewis Dot Structure and if you can kind of tell me what kind of rules you're using or why you are doing the things that you are doing. That would be helpful. After you build the Lewis Dot Structure, then I would like for you to build the geometry, kind of like what you've done in the lab, with marshmallows and toothpicks. Just tell my why you do the things that you do. I will probably ask you questions throughout the time. Okay? Do you understand everything?

G: I think so.

I: Okay, let's go ahead. If you could go ahead and draw the Lewis Dot Structure for water [H_2O]. Why did you choose oxygen as the central atom?

G: Because there is only one of them. Generally if there is only one.

I: Okay...if you could build the structure. What are you having the marshmallows represent?

G: The marshmallow is the oxygen. These [toothpicks] I would assume would be the electrons. I know how to draw them, but I'm not sure how they are....electron pairs or bonds.

I: Why did you put them in that shape?

G: Because, when you've got four, they all have to be in different planes.

I: Okay.

G: Except for two of them, they are all pretty much in the same plane.

I: Okay, what is the shape? Do you know?

G: Tetrahedron. I think.

I: Okay, um, what do you think affects the shape of the molecule?

G: The, um, number of electrons.

I: Okay. Um, do the lone pairs affect the shape at all?

G: Yes, and the bonds whether they are single bonds or multiple bonds.

I: Okay, how do the electrons and lone pairs affect the shape?

G: The lone pairs...well you have to add up the number of lone pairs, how many single bonds, and how many multiple bonds you have. When you add all of those up, that tells you whether you have a linear or a tetrahedral or .....

I: Okay. I will go ahead and take this. And you can get started on the second one, "S-O-3".....what are you doing right now?

G: Writing down how many valence electrons are in each atom. Then you add two electrons because of the two negative.

I: Okay.

G: ...[counting]..."S" will be the central atom with the oxygens all around it. [counting]...six for the bonds....

I: Okay, what, um, does the Lewis Structure represent to you?

G: How many electrons..or valence electrons, actually, I guess, are in the molecule.

I: Okay. Um, if you could go ahead and build the structure. Just build it.

G: Draw it too?

I: Just build it. You don't have to draw it.

G: [building]....

I: Okay, what is that marshmallow?

G: Its the sulfur.

I: Okay, what are each of the toothpicks?

G: Bonds or pairs of electrons.

I: Okay. What shape is that ?

G: This...I can't remember what it is for three.

I: Okay, does the lone pair on the sulfur affect the shape?

G: Sure.

I: How does it affect it?

G: Um, if you didn't have it, then it wouldn't....there's four...I messed up.

I: Okay, so how does the lone pair affect the shape?

G: If it didn't have the lone pair then it would look just like the one I just had [trigonal] when I screwed up.

I: Okay, um, let's see, why do you think shape is important?

G: I have no idea. I guess it just gives you an idea of what it looks like. I guess.

I: I'll take this one, and go ahead and do the next one.[CO_3^{2-}]

G: ...[drawing]....

I: How do you know how many electrons to put around each of the oxygens?

G: Each one has to have eight. Everything has to have eight, except hydrogen and I believe group 14 is an exception.

I: Okay.

G: But, pretty much everything has to have at least eight around it. And then your bond counts as two toward each...either one of them. [counting] ...I believe if I just have extra I put them on the central atom. Is that right?

I: Okay. Why, um, did you put them on the central atom?

G: Because they told me that extra ones [electrons] go on the central atom.

I: Okay. And if you could go ahead and build that one for me.

G: ...[building]...

I: How do you know where to put the toothpicks?

G: Well, if you have six of them, then you will have two go up...straight up and down in the same plane. The other four, you have two coming toward you and two coming away from you.

I: Okay. Where would the oxygens be located?

G: Connected? At the end of every one of the points...not all of them...but on three of them. I'm not sure which ones. She hasn't taught us much about that.

I: Okay, what kind of shape is that?

G: Um, octah....something like that.

I: Okay, all right, um let's do the next one...the last one. Draw the Lewis Structure. [XeF_2].

G: ...[drawing]....

I: What are you writing down right now?

G: 14 because there are two fluorines. And each one has seven...[counting]...

I: Okay. What does that represent? What does that Lewis Dot Structure represent to you?

G: The molecule of XeF_2.

I: Okay. Could you go ahead and build it for me using the marshmallows and toothpicks.

G: Its just like the last one, considering that I did it correctly.

I: Okay. What do you have to think about when you are going from a Lewis Dot Structure to actually building the model.

G: Just count up your bonds, multiple bonds, and lone pairs around the central atom. Whatever it adds up to is how many "sticks" you'll need off of the central atom.

I: Okay.

G: As long as you remember how they all go....if there's three it takes a pyramid shape. If there's four, its the same thing...

I: Why did you choose that shape?

G: Well, there is six of them, so...to build it, just do the two up and two down and two at you and two back.

I: Okay.

G: That's why.

I: Do you think that the lone pairs affect the shape of that molecule?

G: Yeah.

I: Does anything else affect the shape of the molecule?

G: Lone pairs and bonds. Lone pairs will always affect the shape.

I: Why do you think that?

G: Because you have add up your lone pairs, bonds and multiple bonds. So if you have any lone pairs its going to change the shape. Plus, I mean, when you do the thing where you show molecular geometry, you pull them off ...your lone pairs.

I: Okay. Um, have you ever worked with Lewis Dot Structures and molecular geometries before?

G: No.

I: Okay. What have you learned in class or in lab, that has helped you understand this concept.

G: I don't know. We just started building them today. It just seems pretty simple to me.

I: Is there anything else that you would like to add? Well, thank you for your time.

Research Transcriptions - Physical Chemistry Student

Student #1 - McKenna, Female, December 17, 1997

I: What I'm doing is I'm doing a research project for my honors thesis. I'm a chemistry education major. I'm getting ready to do my student teaching. I plan and hope to teach high school chemistry. What I'm doing is I'm having students write Lewis Dot Structures and then actually build models using marshmallows and toothpicks of the Lewis Dot Structure. Um, the first thing that I need for you to do is, there is a consent form. Let me go ahead and read it. It says, "We are asking for your participation in a project that will help us understand how students learn certain chemistry concepts and how instruction can be changed to improve student understanding. Your participation in this project will not affect your grade in the course. Thank you for your assistance. We appreciate that you are willing to take the time to participate in this project. " I just need for you to sign this. And what will happen is that there are four different compounds and we'll just do one at a time. I will ask you questions along the way while you are doing it about what you are thinking. Let's go ahead and get started on the first one. [H_2O] If you could just draw the Lewis Dot Structure and tell me what you are thinking along the way.

M: If I can do it (laughing)....

I: Why did you choose oxygen as the central atom?

M: Because there is only one of them.

I: Okay. Why did you put two sets of lone pairs on the oxygen?

M: Because I have to have eight electrons. And the hydrogens only have one.

I: Okay, if you could go ahead and try to build the model with marshmallows and toothpicks.

M: This is a good idea! I love marshmallows.

I: What are you having the green marshmallow represent?

M: Oxygen.

I: Okay.

M: This is my hydrogen. I don't know how I'm going to put the lone pairs on there. Um....[building]...these are my lone pairs.

I: Okay. Why do you have it as a bent shape versus a linear shape?

M: That's just the way I've been taught to draw them. That's the way I did my Lewis Structure.

I: Okay. Do the lone pairs affect the shape of the molecule?

M: I don't think so.

I: Why do think shape is important?

M: Um, maybe it affects the way it bonds with other things. Like with water, it affects how it attaches.

I: Okay. Go ahead and do the next one. I'll take that from you. [SO_3^{2-}]..... Are you done?

M: I guess. I haven't done this in forever.

I: That's okay. What kind of rules did you use when you were drawing the Lewis Dot Structure?

M: Well, "S" was the only one of those so it was the central atom. And the negative two charge is around the whole thing so it goes on the outside [of the drawing]. I'm not sure if there is supposed to be a lone pair here or not.

I: Okay. If you could go ahead and build the....molecular model please. What is the pink marshmallow representing?

M: The pink one is sulfur. The green ones are oxygen.

I: Why did you choose that shape?

M: Because...its like the way I drew it, but to me it looks more balanced this way.

I: Okay, um ,what does the Lewis Dot Structure represent to you?

M: You know, well, like how maybe something else is going to bond to it. Like where it will bond to it at. And, you know how many pairs of electrons are taken up by bonds.

I: Okay, what affects shape?

M: I don't know.

I: Okay. Let's go ahead to the next one. [CO_3^{2-}]...what did you give this drawing a double bond?

M: ...[drawing]...um, something tells me that it needs to go there. I'm not real sure why.

I: Okay...Does it matter which of the oxygens has the double bond?

M: No.

I: Okay. If you could go ahead and build the molecular structure.

M:...[building]

I: What are the toothpicks representing?

M: A bond.

I: Okay. Does the double bond affect its shape?

M: No.

I: Okay. Why did you choose that shape?

M: It just looks the most sensible. I mean to have this atom straight out of it.

I: Okay. Um, we'll go ahead and do the last one. [XeF_2] What are you thinking about?

M: Whether that needs anymore, whether Xenon needs anymore bonds than just the two already on there. It already has eight....I don't know. I needs eight rather.

I: Okay. Why did you choose to have two double bonds?

M: Well, it's [Xenon] a noble gas, so its full. So, it needs eight electrons. I just don't know if they are double bonds or lone pairs. I can't remember.

I: Okay. Um, what kinds of things do you have to think about....wait, go ahead and build the model. We'll come back to that question...

M: I guess I could've used the big marshmallows too.

I: What types of thing do you have to think about when you go from a Lewis Dot Structure to building the model?

M: I think that you need to think about what type of shape it is when it is drawn. I think that it needs to be that shape when you build it too so you know. So you can get the reality of it.

I: Okay. With this particular structure, is it linear or bent?

M: The way I drew it, I drew it bent, but I don't know if its really supposed to be or not.

I: Okay. What's the difference between being bent and linear? What causes the shape?

M: Um, it would be the interaction between the molecules. Um, I don't know.

I: Okay. Thinking back, you have been taking chemistry classes for a long time now, what have learned either through class or lab or experience that helps you to understand these concepts?

M: Um, I've had a lot of practice drawing Lewis Dot Structures, especially with Organic, like drawing the resonance structures and Lewis Dot Structures. How the resonance forms really helps.

I: Okay. Is there anything else that you want to add?

M: Nope.

I: Well, thank you for your time.

Research Transcriptions - Professor

Professor #1 - Dr. Storhoff, Male, December 18, 1997

I: Okay, this is our consent forms. Let me read it to you. It says, "We are asking for your participation in a project that will help us understand how students learn certain chemistry concepts and how instruction can be changed to improve student understanding. Thank you for your assistance. We appreciate that you are willing to take the time to participate in this project."

S: I'll sign it. Okay.

I: Okay, um, what we are going to do is that we have four different structures. And what I'm going to ask you to do is to draw the Lewis Dot Structure of each and to build them using the marshmallows and toothpicks to build the actual model and tell me what you are thinking and the rules that you are using. Understand?

S: Yeah, no problem!

I: Okay, the first one is water [H_2O]. If you could draw the Lewis Dot Structure for me please.

S: Okay.

I: Okay, why did you choose oxygen as your central atom?

S: Um, because, uh, hydrogen will only have one bond. And, um, and any other choice, you would have to have two bonds with the hydrogens.

I: Okay, um, if you could go ahead and build the structure using the marshmallows and the toothpicks.

S: [building the structure]

I: What do the green marshmallows represent?

S: These are going to be the hydrogens. And...yellow ones for the lone pairs.

I: What shape is that?

S: Well, that's a...that's a tetrahedron, for the number of faces.

I: Okay, what causes the shape of the molecule?

S: Well, the, um, the easiest way to at least think about it is the repulsions. You have a pair of electrons here and here. And you have a pair to the electrons, you have pairs of electrons here, here, here, and here. And since they are negatively charged they will repel each other and try to get as far away from each other as they can i.e. minimize the repulsive energy. And this approximates the minimum shape. Now it can also be explained in another way using how affective the orbitals are in overlapping each other. But this I think is the best way to think about it, the repulsion model.

I: Okay. We'll go ahead and do the next one. [SO_3^{-2}]

S: "S-O-3" [drawing]

I: Why did you choose sulfur as the central atom?

S: Um, in general the least electronegative is the central atom. And, um, typically oxygen will only have two bonds. And, also, it turns out that in nature things tend to be real symmetrical, and so this looks better than something that would look like this. Where sulfur would only have one bond. It tends to be organized in that fashion.

I: Okay. If you could go ahead and build that structure as well.

S: [Building] There we go. Okay.

I: What do the yellow marshmallows represent?

S: This is...again the lone pair. Its the unique. Here are the oxygens. And, uh, sulfur looks too much like an oxygen...but that's the way it is when you only have so many...you should have some colored pencils or something...

I: [laughing]..Okay, why did you choose that shape?

S: Well, again, if you think about the central atom it has a pair of electrons, a second pair, a third pair, and again here's the fourth pair. And so the least...the way that the repulsion will place the atoms and the pairs as far away from each other as possible. Which gives...basically a tetrahedron.

I: Why is shape important?

S: Um, well, in the grand scheme of things, function follows the shape. So , a classic example would be the fact that, um, isomers for example, cis-platinum with the amines or ... a cancer drug that we've tried. And of course there are many biochemical examples and pharmaceutical industry looks very specifically at the shape of the molecule. And the shape of the molecule, uh, or the shape of the species depends... or will dictate how it tastes or how it smells. Camphor, for example, when you think of camphor it comes in two forms. The D and the L, I've forgotten which one is the camphor we think of, the other isomer has a much different sensation.

I: Okay. The next one...

S: "C-O-3" [drawing and counting]

I: How did you know that there was a double bond between the carbon and the oxygen?

S: Um, the four elements: carbon, nitrogen, oxygen, and fluorine will have octets, if at all possible. And it is certainly possible, all you need to do is move one pair from here to over here to a double bond. And it has the octet rule is satisfied. So, I mean, I just used my knowledge of which elements have octets.

I: Okay.

S: {Building the model] So this one, it turns out, has three pairs. So, this one will be approximated with I'll just...I'll just use the small ones for the front of it. The shape, minimized with 120.

I: Does the double bond affect the shape at all?

S: No, as a matter of fact, it would be better to think of this as the...as the average of three resonance forms. And so the real shape is one and a third bonds. So we are having the equivalent of one and a third bonds repelling one and a third bonds repelling one and a third bonds. So it isn't the case where we have a single bond repelling a double bond. We have to look at this as an average forms. So, no.

I: Okay. We'll go ahead and do the last one.

S: Oh the last one! Oh, XeF_2, I love these Xenon ones. [Drawing]

I: What kind of information can you get from a Lewis Dot Structure?

S: Uh, you can get from the Lewis structure, you can go and get the shape and Valence Shell Electron Pair Repulsion. You can get the acid-base characteristic by knowing where the lone pairs are or multiple bonds, so acid-base in the Lewis sense. You can figure out from Lewis structures bond energies plus bond energies. You can get delta H approximations. Oh, let's see what else you can do. Oh, you can figure out if they have dipole moments or not. Um, I think those are the major things: the general shape, the acid-base characteristics, um, I really left out...hybrid orbitals.

I: Okay, if you could go ahead and build the structure.

S: This is just like this...[building]. There are three lone pairs. The question here of course is where are the lone pairs. With XeF_2, I'm going to let the lone pairs be these, um, orange or yellow, and the fluorines be the green [marshmallows].

I: How did you know where to put the fluorines?

S: Well, this again is a matter of repulsion. It turns out that a lone pair is in an orbital that is a little more diffuse than a bond pair. The reason for that is that a bond pair is located between two nuclei. And so this bond pair is between two nuclei. Now, what would happen if we moved...if we made a change here and put ...let's look at this one first. So, this bond pair...this lone pair is 120 degrees from that lone pair and 120 degrees from that lone pair. And, this lone pair is at 90 degrees to this bond pair and 90 degrees to that bond pair. So the lone pairs are 120 degrees apart. And, at 90 degrees we have bond pairs, if we make a change here, if you are to move this around, suddenly this lone pair would have three, two lone pairs and one bond pair, at 90 degrees. Since a lone pair is in a bigger orbital, we'll have to minimize the number of bond pairs or lone pairs at 90 degrees. And the way to minimize the number at 90 degrees is to make sure that the lone pairs are always on the equatorial rather than the axial position. Because, any thing, any lone pair that's in an equatorial position will have only two at 90 degrees, but any time you would have a situation where the lone pair were axial, it would automatically have three at 90 degrees. So, again, its a matter of repulsion and in this case its a matter that the lone pair is in a larger orbital.

I: Okay, in your experience in teaching general chemistry, teaching this concept, what kind of challenges do you think the students have with this concept?

S: Well, um, almost every structure feature or bonding feature associated with atoms and ions is an abstract concept. And so even though if we build models and make analogies, its still very abstract. And, it turns out that often times, except for students who come with good backgrounds from very good high schools, its a topic that they haven't studied extensively. Maybe they have done some with octets but not with molecules. And often times even students who come from good programs haven't looked at the shapes. So, its something new. Its new and not closely related to mathematics or any other course that they have taken and its not closely related to a biology or any other related field. And, so I think that its the newness of it and the abstract nature of structure and bonding.

I: Okay. Well, that's it. Thank you very much for your time.